Silicon Power MOSFETs

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Abbreviations & Acronyms

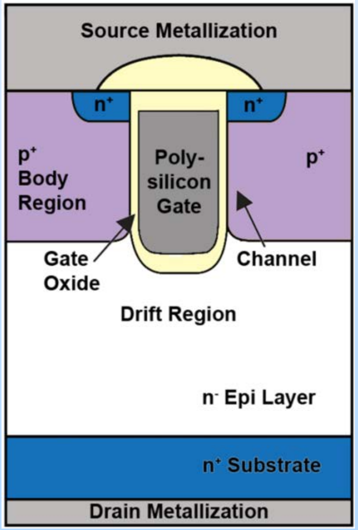
Acronym	Definition
BV_{DSS}	Drain-Source Breakdown Voltage
COTS	Commercial Off The Shelf
EEE	Electrical, Electronic, and Electromechanical
ETW	Electronics Technology Workshop
FY	Fiscal Year
GCR	Galactic Cosmic Ray
I_D	Drain Current
I_{DSS}	Drain-Source Leakage Current
I_G	Gate Current
LBNL	Lawrence Berkeley National Laboratory cyclotron facility
LET	Linear Energy Transfer
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NEPP	NASA Electronic Parts and Packaging

Acronym	Definition
NESC	NASA Engineering & Safety Center
PIGS	Post Irradiation Gate Stress
RHA	Radiation Hardness Assurance
RTN	Random Telegraph Noise
Si	Silicon
SJ	Superjunction
SOA	State Of the Art
SWAP	Size, Weight, And Power
TAMU	Texas A&M University cyclotron facility
TID	Total Ionizing Dose
VDMOS	Vertical Double-diffused MOSFET
V_{DS}	Drain-Source Voltage
V_{GS}	Gate-Source Voltage
V_{TH}	Gate Threshold Voltage

Outline

- Power MOSFET Task & Technology Focus
- Task Roadmap & Partners
- Recent Results
- Summary & Comments

Trench-style MOSFETs offer application-targeted performance enhancements but are more vulnerable to ion-induced TID degradation

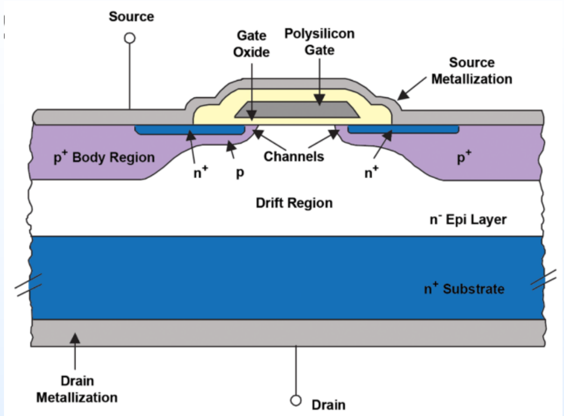


Lauenstein, IEEE REDW 2013

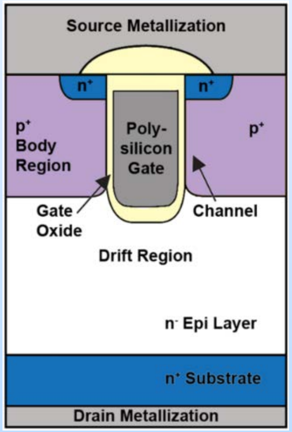
Silicon Power MOSFET Technology

Planar Gate VDMOS

- Dominates rad-hardened offerings
- Prior NEPP efforts helped to expand market



Drawings from:
Lauenstein, IEEE REDW 2013

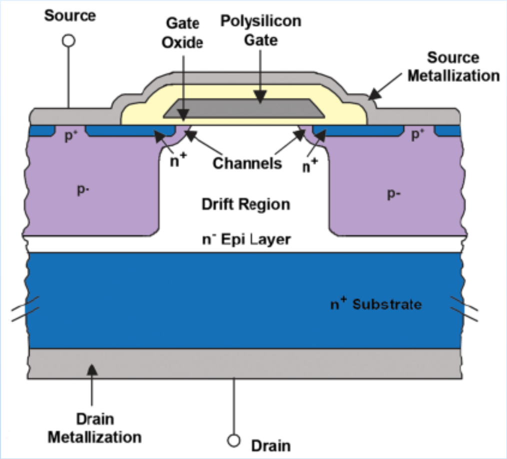


Trench Gate VDMOS

- Dominates COTS lower-V applications
- Only 1 rad-hardened offering

Trench SJ VDMOS

- Emerging technology

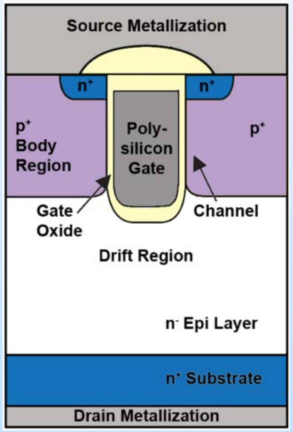


Superjunction (SJ) VDMOS

- COTS competes with IGBTs
- Near-term availability of rad-hardened options for 100V-650V (100V – 250V out now…for a $$)

Silicon Power MOSFET Technology

- **NEPP task focuses on RHA of state-of-the-art Si power MOSFETs offering competitive edge over older planar gate VDMOS**



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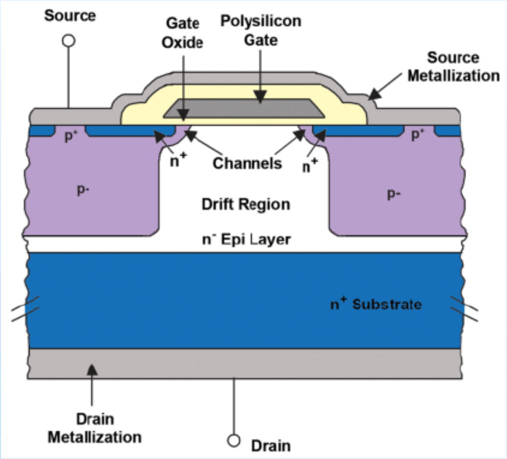

Superjunction (SJ) VDMOS

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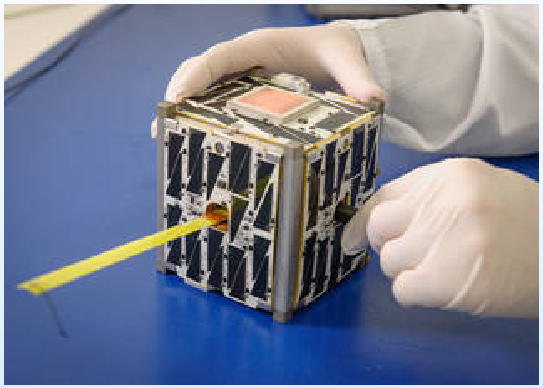
- Near-term availability of rad-hardened options for 100V-650V applications

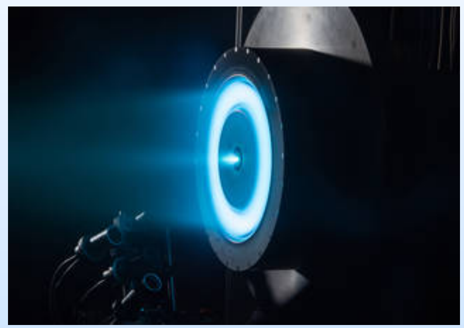
Motivational Factors

Images courtesy of NASA



CubeSATs

High Voltage Instruments



Solar Electric Propulsion

Commercial Space

- **Game-changing NASA approaches are demanding higher-performance power electronics**
- **SWAP benefits for existing technologies**

Conclusions: We must understand risks of COTS/Auto options;

We must foster industry partnerships to develop rad-hardened options when feasible

NEPP Collaborations

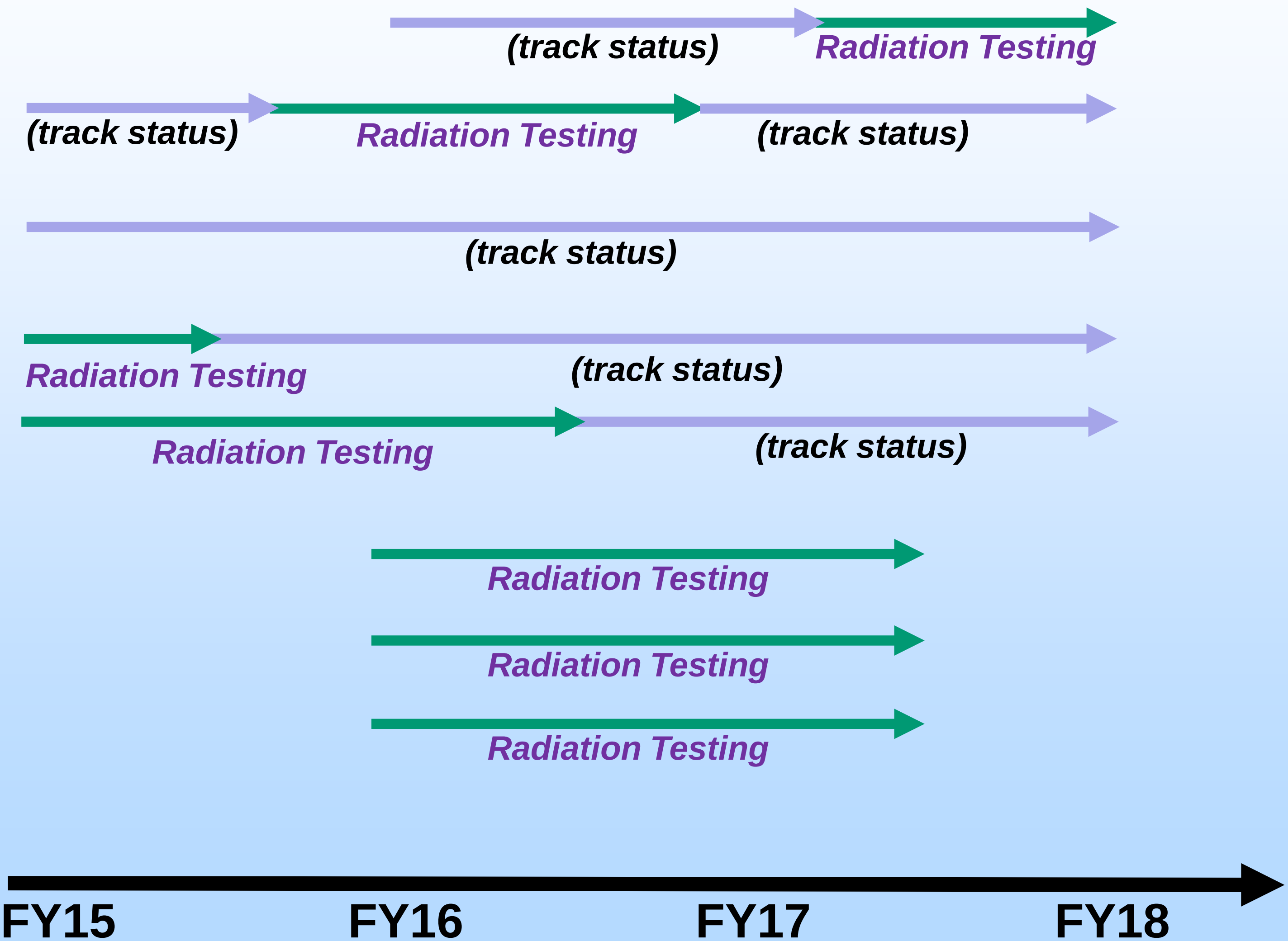
Topic	Agency(ies)/Industry	Description
COTS/Automotive Trench	NESC, Aerospace Corp., Vishay	Radiation evaluation of trench MOSFETs
Rad-Hardened Trench	Infineon/IR	Independent radiation testing of new offering
Superjunction MOSFETs	Infineon, STMicro	Independent radiation testing of new rad hardened SJ MOSFETs
planar VDMOS	Fuji, Microsemi	Independent radiation testing of rad hardened new offerings: High voltage is a priority (500 V and up)

- **Informal relationships include assisting end-users:**
  - Understanding radiation effects and sharing test data on power MOSFETs to aid parts selection
  - Best practices, “rules of thumb” for application conditions

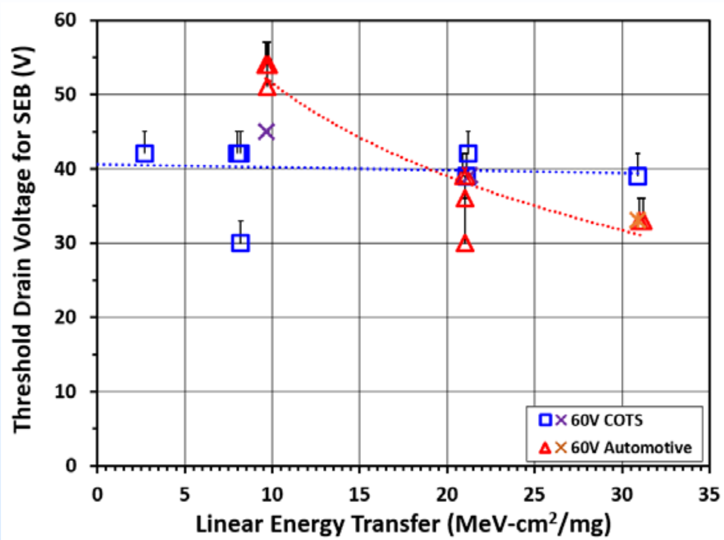
Silicon Power MOSFET Roadmap

Rad Hardened
- **STMicro superjunction**
- **Infineon superjunction 100 V, higher-V targeted**
- **Fuji JAXA-R VDMOS high voltage**
- **Microsemi i2MOS**
- **Infineon (IR) R8 trench**

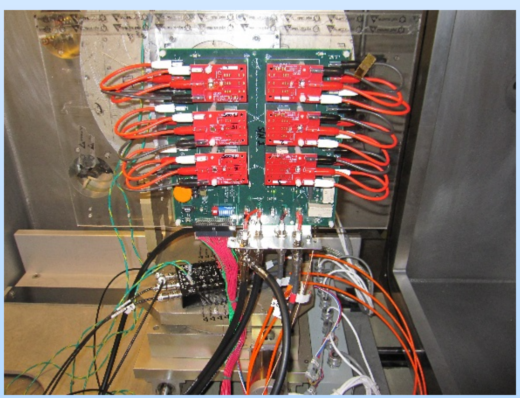
COTS/Alternative Grade
- **Vishay Trench**
- **On Semiconductor Trench**
- **NKP Trench**



Silicon Trench Power MOSFET Catastrophic Failure Modes



Comparison of n-type 60V trench MOSFET SEB thresholds

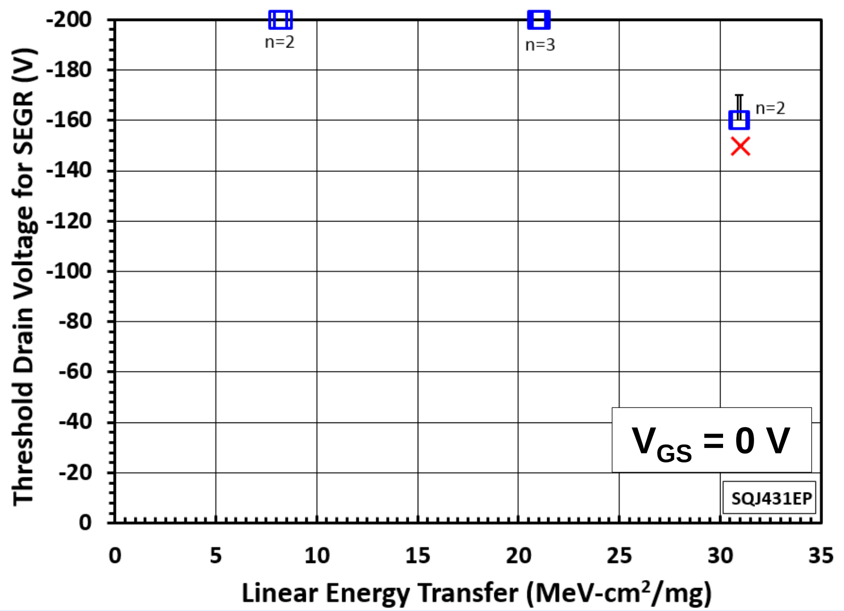


Trench MOSFETs on test board at Lawrence Berkeley National Laboratory accelerator facility

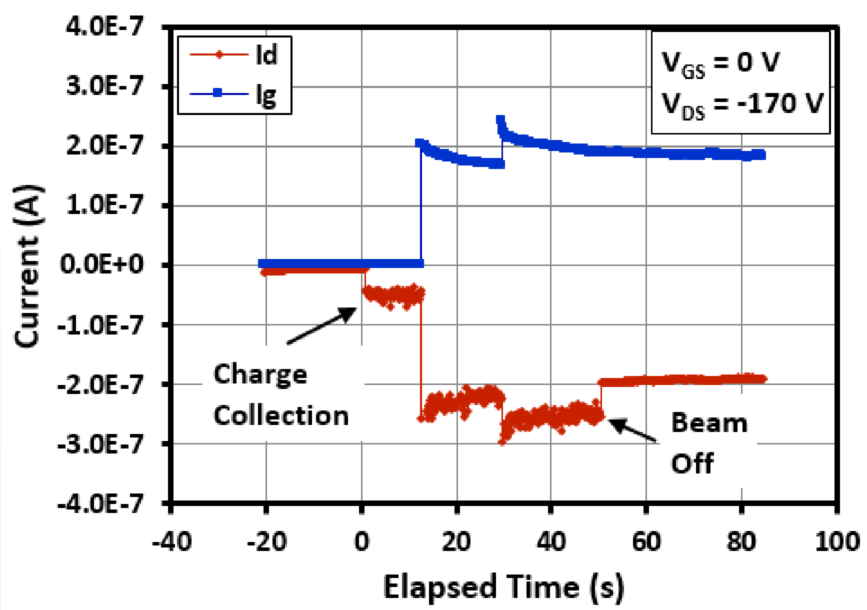
- **COTS/Automotive:**
  - **Collaborative effort with NESC**
  - ***Part-part variability requires larger test sample sizes, possibly more derating***
  - **N-type – SEB**
    - ***Onset LET varies within manufacturer***
      - ***Cannot generalize test results***
    - Even for LETs below GCR "iron knee", must use these 60 V parts at < 50 %
  - **P-type – SEGR**
    - Often safe at higher % of rated voltage

P-Type Trench Power MOSFET Test Results

Vishay SQJ431EP Automotive: -200V, 12A, 213 mΩ



SEGR Response Curve

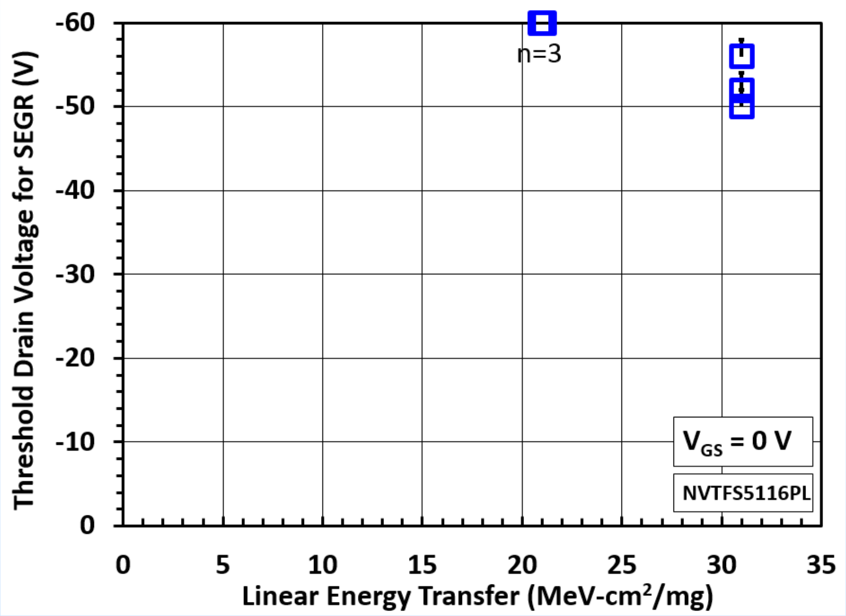


Strip Tape During Run

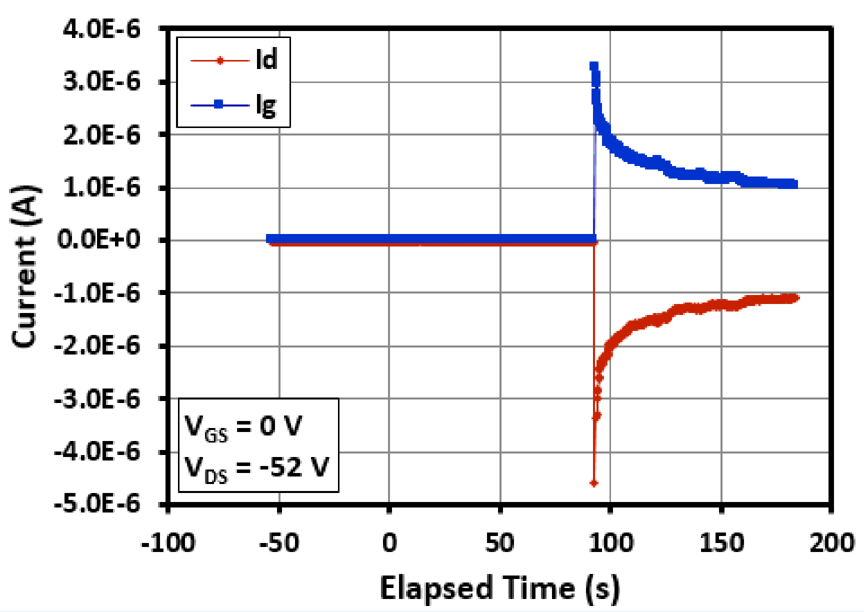
- **SEGR with 886 MeV krypton (LET = 31 MeV·cm²/mg) at 75% of rated voltage**
  - "×" in left plot marks failure after first beam run at -150 V: threshold thus not found.
  - 2 samples failed on PIGS; 1 during run (gate-to-drain) (right plot)

P-Type Trench Power MOSFET Test Results (cont'd)

On Semiconductor NVTFS5116PL Automotive: -60V, 14A, 52 mΩ



SEGR Response Curve

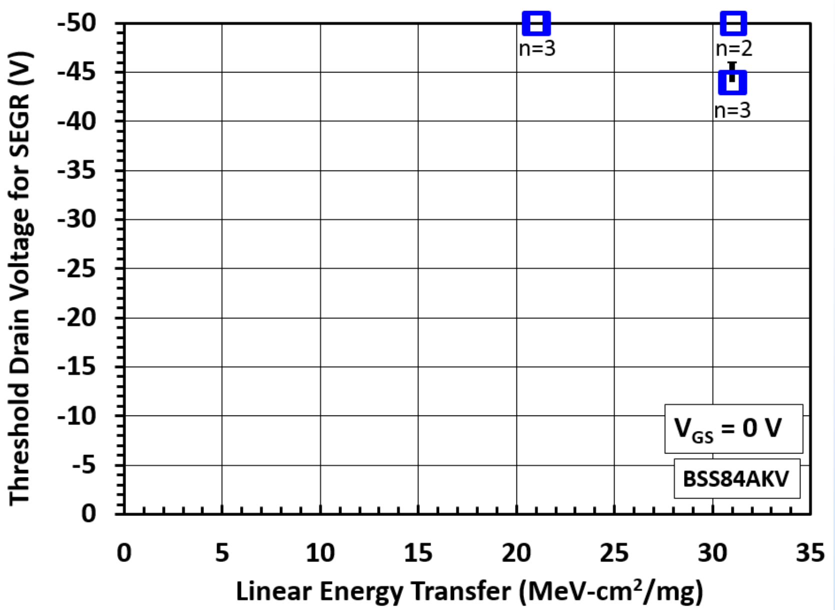


Strip Tape During Run

- **SEGR with 886 MeV krypton (LET = 31 MeV·cm^2/mg) at 83% of rated voltage**
  - All 3 samples failed during run (ex/ right plot)
  - ***Part-to-part variability: may require additional derating over standard 0.75 factor***
    - Ex/ 0.75*(-50 V) = -37.5 V but 99/90 one-sided tolerance (KTL) yields -30 V

P-Type Trench Power MOSFET Test Results (cont'd)

Nexperia BSS84AKV Automotive: -50V, 170mA, 7.5 Ω

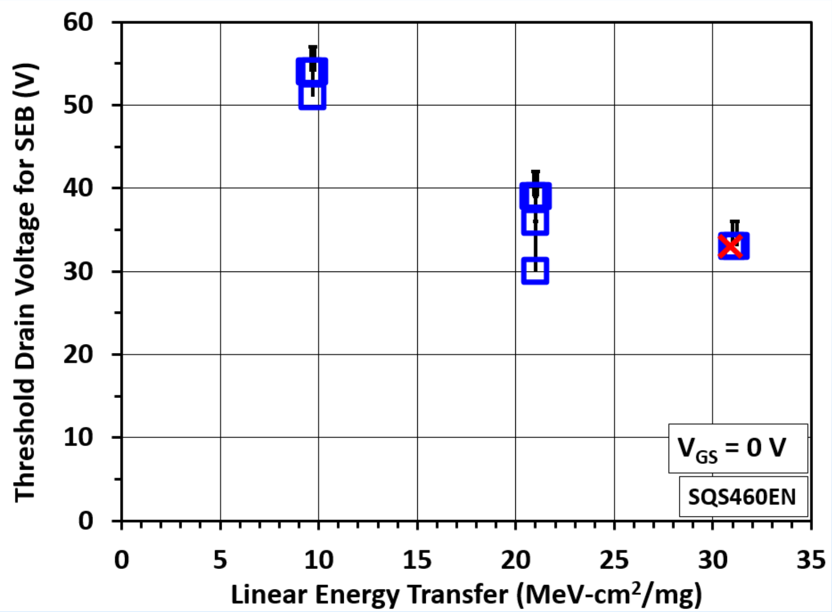


SEGR Response Curve

- **SEGR with 886 MeV krypton (LET = 31 MeV·cm^2/mg) at 88% of rated voltage**
  - All 3 samples failed during run (ex/ right plot)
  - Part-to-part variability: may require additional derating over standard 0.75 factor
    - ***Cannot rule out bimodal distribution***

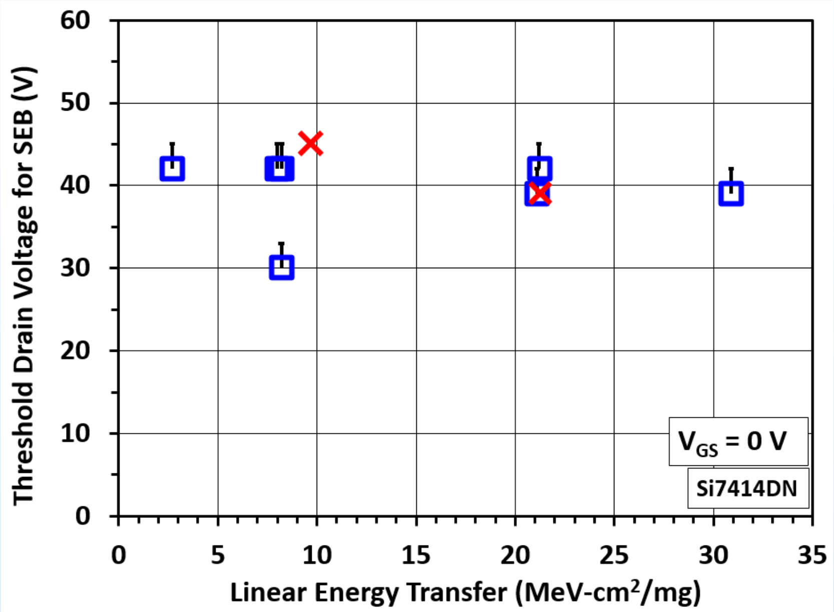
N-Type Trench Power MOSFET Test Results

Vishay SQS460EN
Automotive: 60V, 8A, 36 mΩ



SEB Response Curve

Vishay Si7414DN
COTS: 60V, 8.7A, 25 mΩ

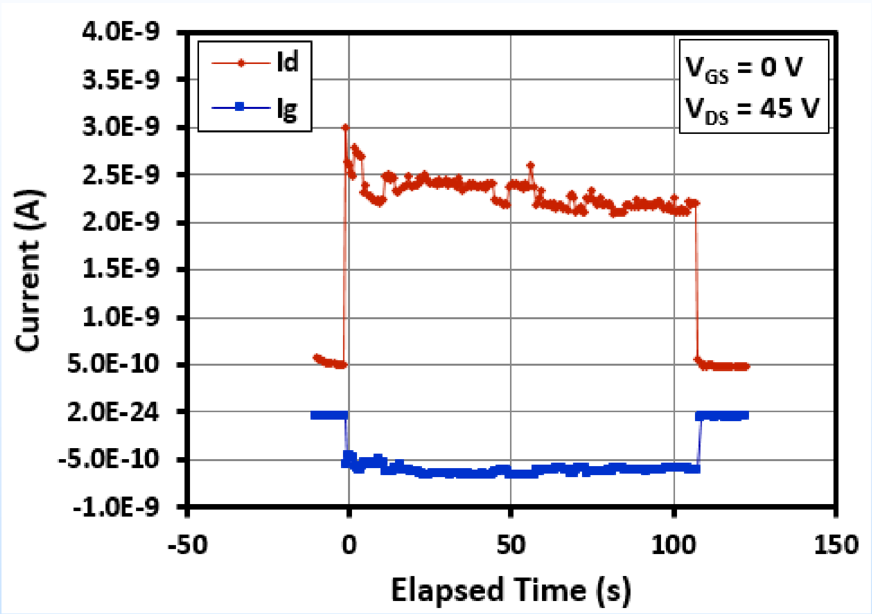


SEB Response Curve

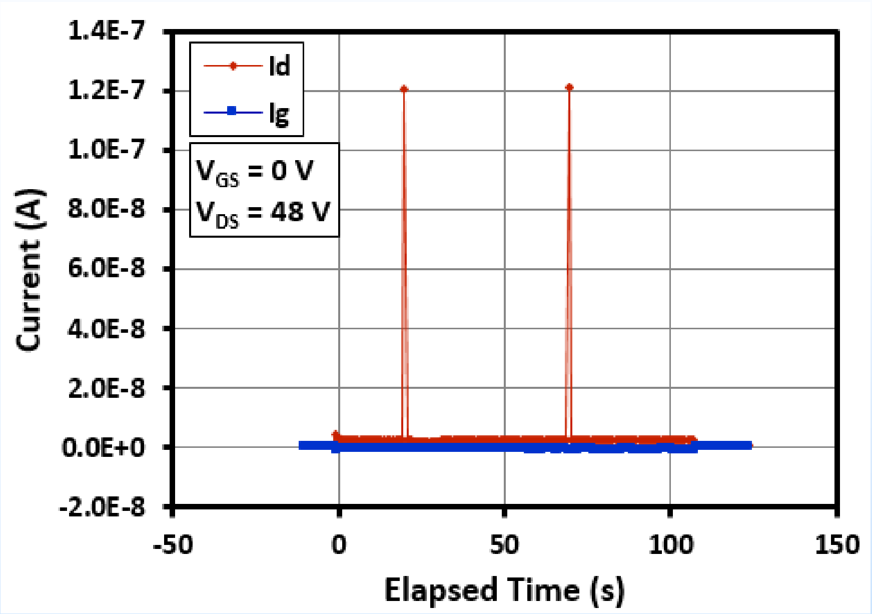
- **SEB with ions below the GCR "iron knee", at 50% of rated voltage**
  - Possible risk of SEB in proton environment
  - Part-to-part variability/bimodality continues to be a concern

N-Type Trench Power MOSFET Test Results: 200 MeV Protons

Vishay Si7414DN COTS: 60V, 8.7A, 25 mΩ



Strip Tape During Run: Charge Collection Only



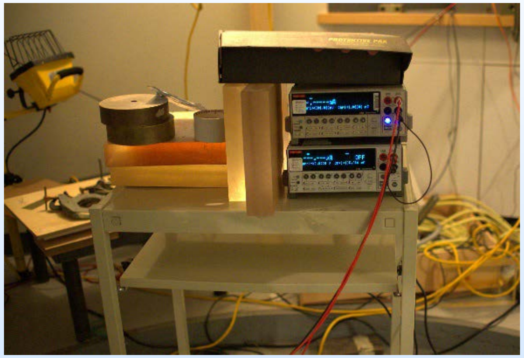
Strip Tape During Run: Current Spikes

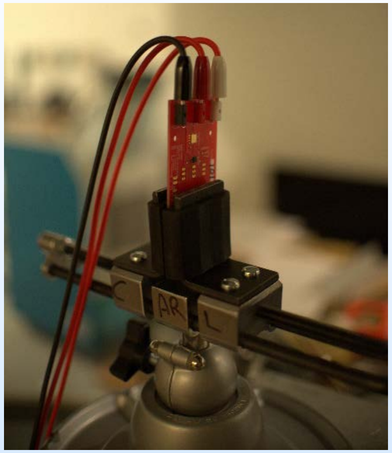
- **Onset V_{DS} for current spikes from 200-MeV protons is similar to that of SEB from heavy ions**
  - Lack of stiffening capacitor may have allowed V_{DS} quenching

N-Type Trench Power MOSFET Test Results: 200 MeV Protons (cont'd)

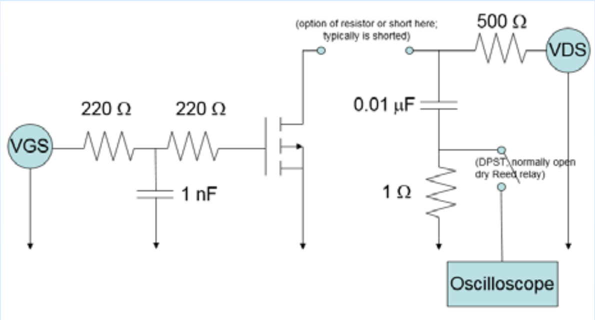
Vishay Si7414DN COTS: 60V, 8.7A, 25 mΩ

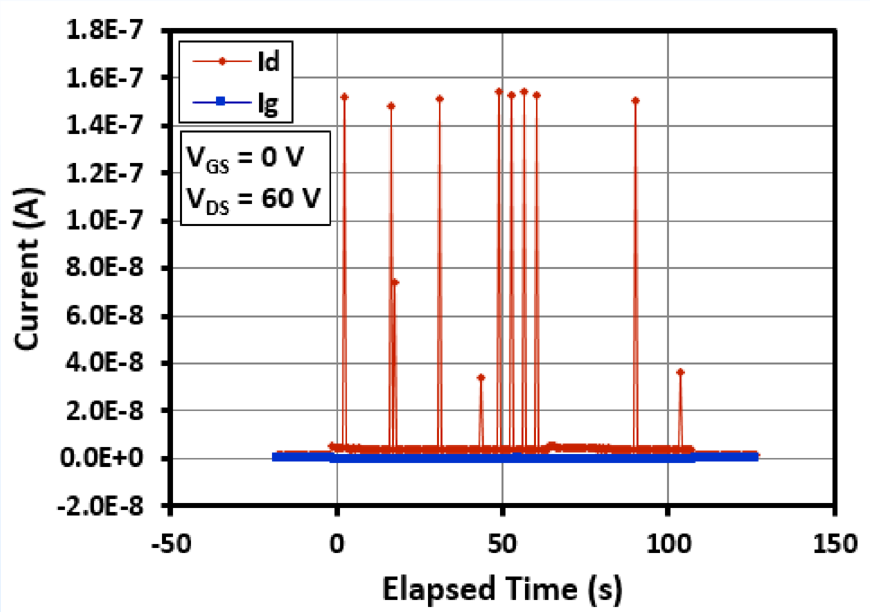
Proton Test Setup





MIL-STD Test Circuit

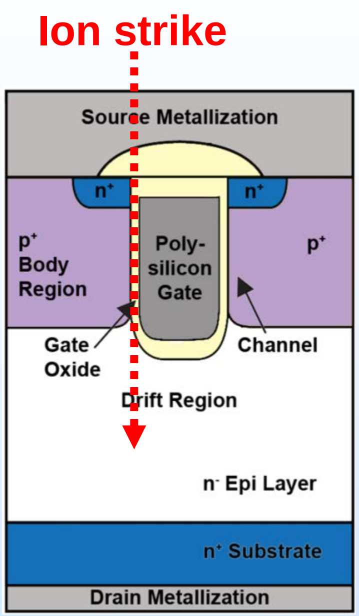




Strip Tape During Run: Increased Current Spike Frequency

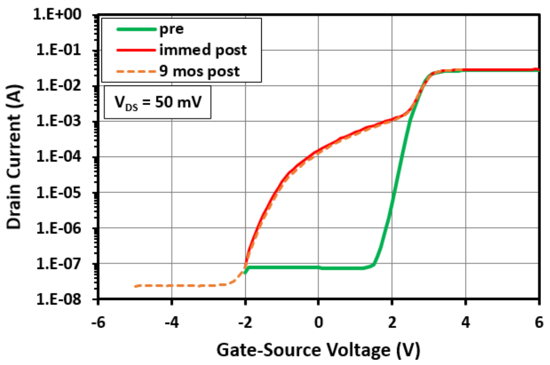
- **Frequency of current spikes, but not magnitude, increases at higher V_{DS}**
  - Additional tests needed to reveal whether spikes are protective-mode SEB events

Silicon Trench Power MOSFET Degradation from Heavy Ions

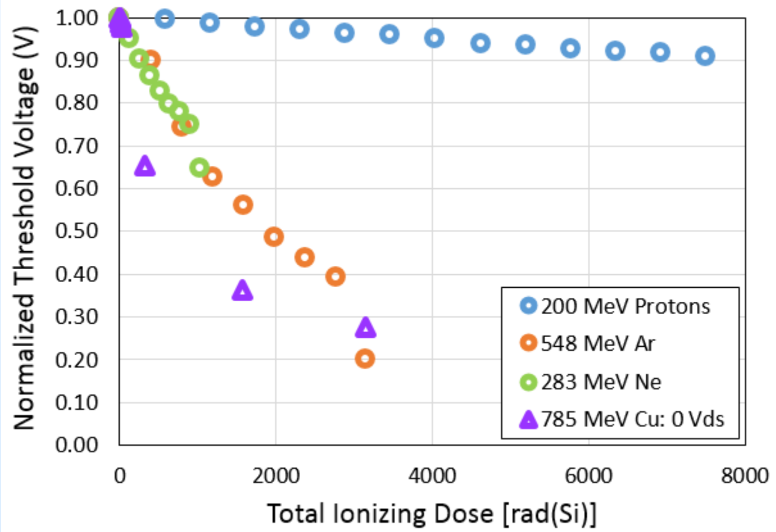


Modified from: Lauenstein, IEEE REDW 2013

- **Non-hardened n-type susceptible to localized dosing degradation**
  - Ion strike through gate oxide locally shifts the flatband voltage, forming a transistor region with lower gate threshold voltage
  - Well-understood phenomenon affecting only n-type transistors
    - Gate threshold shift in p-type swamped by overall lower threshold voltage



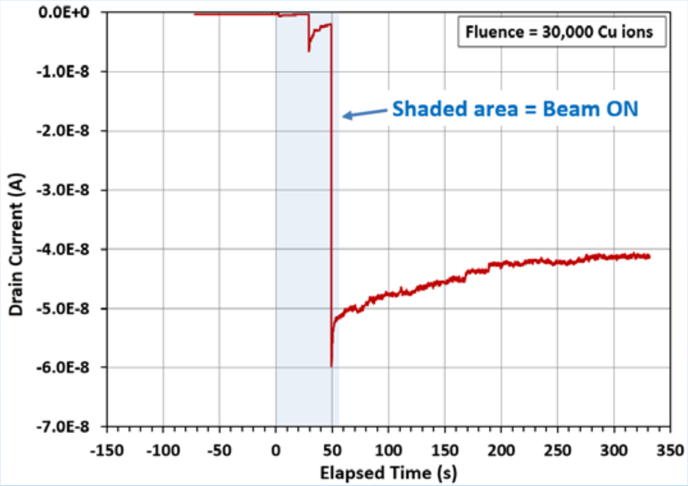
Strikes through gate oxide along channel length form regions of lower V_{TH}



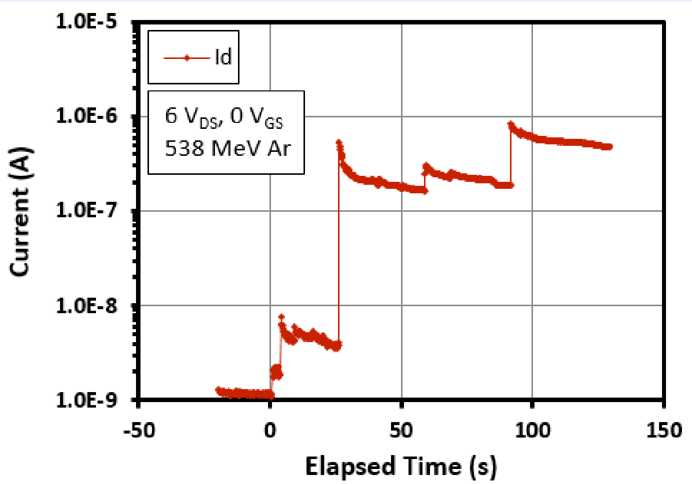
Greater effect on V_{TH} from heavy ions vs. protons

Silicon Trench Power MOSFET Degradation from Heavy Ions (cont'd)

- **Magnitude of effect is primarily voltage-dependent**
  - ***On orbit, unbiased spares are still vulnerable***



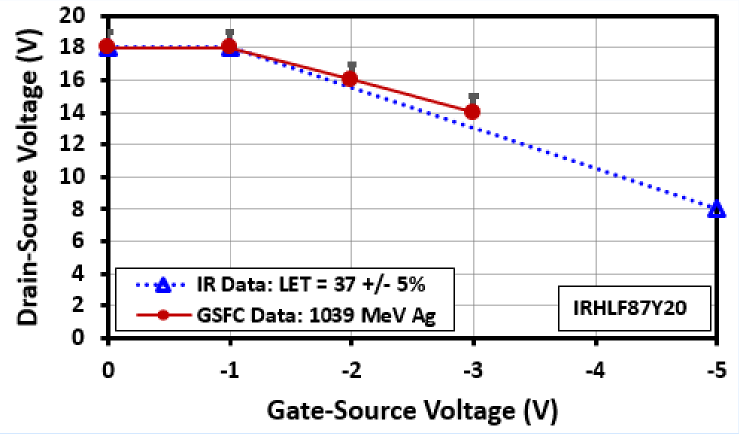
Trench MOSFET drain current during beam run: *0 V applied to all pins*



At 6 V_{DS}, ~3 order of mag. increased I_D after ~6 argon ions through gate oxide

Hardened Trench MOSFET Test Results

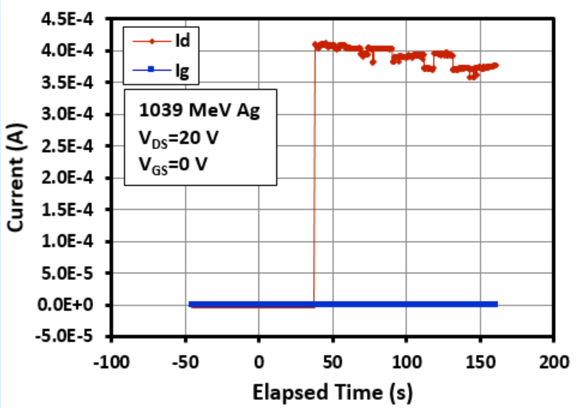
Infineon (International Rectifier) IRHLF87Y20
R8 rad-hardened: 20V, 12A, 32 mΩ



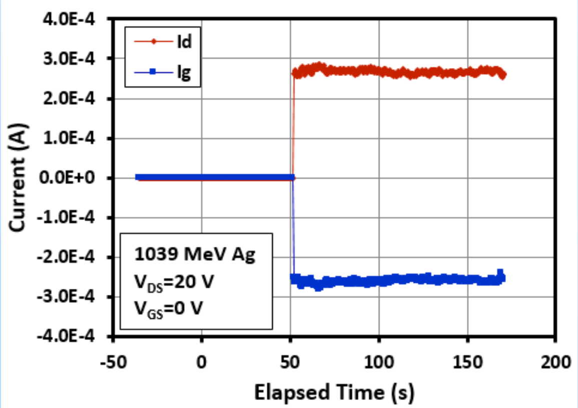
SEE Response Curve

- **First (and only) rad-hardened trench MOSFET**
  - Verified manufacturer SOA
  - ***3 different failure signatures occurred outside SOA***
    - **Greater complexity than planar MOSFETs**

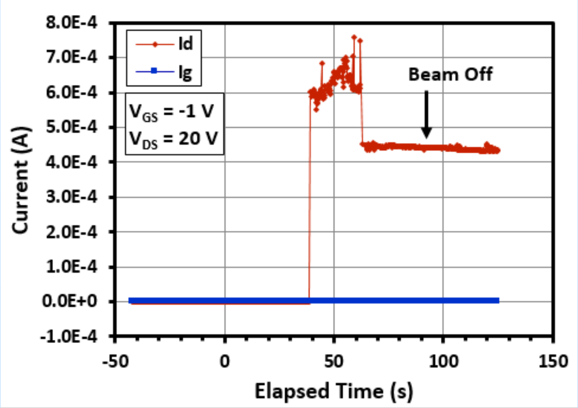
SEB (note RTN-like behavior)



SEGR



SEB with partial recovery



Summary and Comments

- **Commercial and alternative-grade MOSFET usage will continue**
  - Driven by higher risk-tolerant missions & commercial space
  - RHA challenge in light of limited funding:
    - Understand general radiation effects
    - Become wiser at identifying “must test” candidates
      - By application & environment
      - By component itself (voltage rating, type, manufacturer, etc.)
- **Higher-performing radiation-hardened options are on the horizon**
- **Partnering is the key to incentivize manufacturers of rad-hardened parts and to share COTs data**
  - Government
  - Industry
  - Academia